CCD PHOTOMETRY OF VARIABLE STARS IN A SOPHOMORE LEVEL ASTRONOMY LABORATORY

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Abstract

At Michigan State University CCD photometry of RR Lyrae variable stars has been made an important part of a sophomore-level laboratory course for physics and astrophysics majors.

Since the nineteenth century, laboratory exercises have complemented lectures in college level courses in the sciences. Astronomy has been no exception, save that in their subjection to the vagaries of weather, observational laboratories in astronomy have perhaps always differed somewhat from those conducted purely in the laboratory. Much can be learned from examination of celestial phenomena with the eye alone, but the range of astronomical laboratory work can be greatly expanded if telescopes, photometers, or other tools of the astronomical trade are available for student use. Recently, the coupling of CCD cameras to telescopes of small to moderate aperture has opened new avenues for both research and teaching at colleges and universities.

In 1991, it was decided to upgrade the observational component of the Practical Astronomy course at Michigan State University, introducing exercises based upon CCD imaging. This course was taken mainly by physics and astrophysics majors in the spring quarter of their second year of college. The number of students in the class was small, typically between 10 and 15, allowing for considerable individual instruction. These students already had a basic grounding in physics, and most of them had completed one or two introductory lecture courses in astronomy. Nonetheless, unless they were amateur astronomers beforehand, the students may have had only a textbook acquaintance with the appearance of the night sky when they entered the class. In 1992-93, Michigan State University switched from a three-quarter to a two-semester academic year. The observational laboratory of the Practical Astronomy course was, however, retained as part a new semester course which combined lectures and laboratory exercises.

The main instrument used in the laboratory is the 0.6-m reflecting telescope of the Michigan State University Observatory. Built on agricultural land two miles south of the main campus, the observatory is near enough to be accessible to students, but far enough from the campus center to avoid the worst areas of light pollution. Nevertheless, sky glow from Lansing and surrounding communities keeps the observatory skies from being fully dark, a problem which has worsened in recent years. The telescope is equipped with a liquid nitrogen-cooled CCD camera built by Photometrics, Ltd. This camera contains a 1024 x 1024 pixel CCD chip manufactured by Ford/SAIC. When used at the f/8 cassegrain focus, the CCD takes images which are approximately 11 arcmin on a side, with a single pixel corresponding to about 0.7 arcsec. In taking images of sparsely populated star fields, the pixels were often binned 2 x 2 before readout to decrease readout time and to save disk space. The resultant 1.4 arcsec "superpixels", in the terminology of Howell (1992), are still smaller than the typical seeing disk (about 3 arcsec). The right ascension and declination axes of the telescope have encoders which permit accurate positioning of the telescope. There is no difficulty in placing objects of known coordinates near the center of the CCD field. The telescope drive is sufficiently precise that exposures of up to ten minutes usually need no active guiding.

In incorporating CCD imagery into the laboratory, it was intended to introduce students to one of the most important tools of the modern astronomer. With the CCD on the 0.6-m telescope, students can carry out many classical observational projects and derive for themselves results they have previously encountered in their textbooks. However, they can also carry out observations the results of which are not known in advance, and which contribute to the increase of astronomical knowledge. Differential photometry of variable stars is an excellent example of such an endeavor.

As a laboratory exercise, differential photometry of variable stars has several points in its favor. First, there has been no rush by great observatories to take advantage of crystal-clear Michigan skies. In the weather typical of Michigan and surrounding locales, differential photometry can be successfully carried out on many more nights than can absolute photometry. Second, the precepts of differential photometry (Howell 1991, 1992) are relatively straightforward, and can be grasped readily (or eventually) by most students. Third, there are many variable stars which change significantly in brightness on a relatively short timescale, so that variability can be studied during the several weeks in which the students can make observations.

There are many kinds of variable stars which might be chosen for observation in a laboratory of this type: eclipsing binary stars and Cepheids, for example. In our particular case, the selection of field RR Lyrae stars as the principal targets followed from the pre-existence of a separate program of photometry of field and globular cluster RR Lyraes. RR Lyrae variables are pulsating giant stars (Hazen 1986) which have periods in the range of 0.2 to 1 day and amplitudes of about 0.5 to 1.5 magnitudes in V. Photometric observations of these variables can be put to several uses. The *General Catalogue of Variable Stars* (GCVS) (Kholopov *et al.* 1985) lists a number of suspected RR Lyrae stars brighter than 15th magnitude for which pulsation periods are not known. Photometry of these stars can verify their RR Lyrae nature and allow their periods to be found. Moreover, the pulsation periods of many RR Lyrae stars are not constant, but change slowly over time. These changes are not large, but, because RR Lyrae periods are short and many cycles occur in the course of a year, period changes as small as one part in a million can be detected after several years of observation. These minute period changes imply the occurrence of small changes in the density and structure of RR Lyrae stars. So small are these structural changes that they cannot be detected in any other observable quantity. To measure these period changes, RR Lyrae variables must be observed at regular intervals over a span of years or decades. The AAVSO RR Lyrae Committee has undertaken to follow the long term period changes of several RR Lyrae stars in the galactic field. Accurate CCD photometry can contribute to this effort.

The class of 10-15 students was divided into three or four smaller groups. On Mondays, each group took responsibility for making observations on one or two specific nights of the coming week, should the weather on their assigned nights prove clear. The first one or two sessions a group had at the telescope were mainly tutorial, but after that students were expected to find the target star and take data with minimal assistance from the instructor. Students readily appreciated that calibration frames, as well as images of variable stars, must be taken if useful CCD photometry is to be done. Flat field frames of the twilight sky or dome flats were taken every night, as were dark/bias frames. The calibration frames and frames of the variable stars were recorded on exabyte tapes at the telescope. Frame arithmetic for actual calibration was carried out later, on workstations in the Physics and Astronomy Building. Although all students were led through the calibration procedures, it proved too cumbersome to have each student calibrate a small portion of the observations. Instead, the instructor or a single well-trained student routinely handled dark subtraction and flat field calibration.

In obtaining images of the variable stars, several practical considerations were impressed upon the students. First was the need for suitable comparison stars. In addition to the variable itself, each CCD image should include at least two comparison stars. The comparison stars should be roughly comparable in brightness to the variable, so that exposures sufficient to give good signal-to-noise for the variable will also provide good signal-to-noise for the comparison stars. Ideally, the comparison stars should be similar in color to the variable. Although all stars are observed through filters (usually the broad-band V filter in our case), if stars are very different in color the effective wavelength sampled by the filter-CCD combination will be slightly different for each star. Although a single stable comparison star would in principle suffice for differential photometry, one must be certain that the comparison star itself is not variable. A second comparison star provides a check in this regard. With an 11-arcmin field of view and program variables of 11th - 14th magnitude, it usually proved possible to find adequate comparison stars in the same field as the variable, even in the case of variables at high galactic latitude.

One item requiring judgment at the telescope was: How bad can a night be and still be useful for differential photometry? A prime virtue of differential photometry with a CCD is that the variable and comparison stars are observed simultaneously. To the extent that clouds or haze uniformly affect the field of view, their effects can be neglected. Nonetheless, CCD's are not magic, and there are limits to the weather conditions when even CCD observations are not possible. For purposes of this laboratory, the night was considered usable if individual observations of the RR Lyrae stars were uncertain by no more than ± 0.03 magnitude. It was not always possible to tell by glancing at the sky whether this minimal condition was being met. A means of doing quick, if approximate, aperture photometry in real-time at the telescope can help one estimate the quality of the night. Still, one must be ready to throw out a night's data if the final reductions show the night to have been worse than one imagined.

Reduction of the observations was accomplished by the students with the two-dimensional aperture photometry routines in DAOPHOT (Stetson 1987). These reductions could be set up in a "cook book" fashion that was straightforward for students to follow. To keep things simple, in these class exercises I have avoided fields crowded with stars, where the much more complex profile-fitting photometry routines in DAOPHOT would have been needed. At the end of the class, students were required to write a report detailing the observation and reduction techniques employed and discussing the results obtained.

The first time this laboratory was attempted, in the spring of 1991, observations of SS Leonis were obtained which led to a short class publication (Anderson *et al.* 1991). The 1992 running of the laboratory was not so successful. Weather conditions were poor, and I chose a target variable, AQ Leonis, whose complicated double-mode behavior could not be adequately analyzed with only a few nights of data. In 1993, AH Leonis was selected as the target. AH Leonis is listed in the GCVS as a probable RR Lyrae star, but no period is given. The CCD observations confirmed the RR Lyrae nature of AH Leonis, yielding a preliminary period near 0.46 day. However, the light curve of AH Leonis did not repeat precisely from night-to-night, suggesting that the star may exhibit the Blazhko effect, a long, secondary modulation of the primary light cycle. It is planned to continue observations of this star in 1994 to confirm this possibility.

Feedback from students who have taken this laboratory has been positive. "Even more fun than differential equations" read one student's evaluation. The possibility of learning something new about a variable star was an incentive to student enthusiasm.

The possibility of a class publication was another incentive, though one which I tried not to emphasize overly.

In his book *Starlight Nights,* Leslie C. Peltier recorded how his lifelong interest in variable stars was inspired by a footnote at the end of William Tyler Olcott's *Field Book of the Stars*. The footnote encouraged readers "willing to aid in the great work of astrophysical research" to communicate with the author regarding "valuable and practical scientific research work" which could be accomplished with a small telescope. As those who know Olcott as one of the founders of the AAVSO will have guessed, that valuable and practical scientific research was the visual observation of variable stars. Intrigued by Olcott's invitation, Peltier wrote to him and was eventually launched upon the variable star observations which he carried out with such success. Perhaps few of the students who pass through this laboratory will be so taken with variable star observing as was Peltier, but it is hoped that many of them will leave the course with increased enthusiasm and appreciation for "the great work of astrophysical research."

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